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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Provides procedures for determining the dynamic performance of weapon components to aid in correcting design problems.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

AMSTE-RP-702-102
*Test Operations Procedure 3-2-826 — 15 July 1985
AD No.

KINEMATIC TESTS OF SMALL ARMS

1. SCOPE. This TOP describes methods to determine the dynamic performance of selected weapon components to aid in correcting design problems. This is done by: (a) recording the displacement of gun components relative to time and distance through the use of a displacement-time camera; and (b) measuring the impulse and recoil of small-caliber weapons by means of the ballistic pendulum. The pendulum discussion is limited to the five-wire and three-wire suspended pendulums.

Various methods and instrumentation, both optical-mechanical and electro-optical, may be used for recording the dynamic characteristics of weapon mechanisms. The displacement-time camera used in kinematic evaluations (fig. 1) is an optical-mechanical instrument that records displacement of gun components with respect to time. The Optron (fig. 2) is an example of an electro-optical device used to record displacement versus time. From these records, the velocities, accelerations, frequencies, rates of fire, momentums, and energies can be calculated. Investigations are conducted on new weapon concepts and, in many instances, in product improvement tests of standard mechanisms.

The ballistic pendulum is sometimes used during safety evaluations to measure the recoil energy of hand-held and shoulder-supported weapons. It is also used to determine muzzle-deflection energy resulting from the use of various types of muzzle attachments. A ballistic pendulum with a rifle internally mounted is shown in Figure 3.

*This TOP supersedes TOP 3-2-826 dated 9 October 1973.

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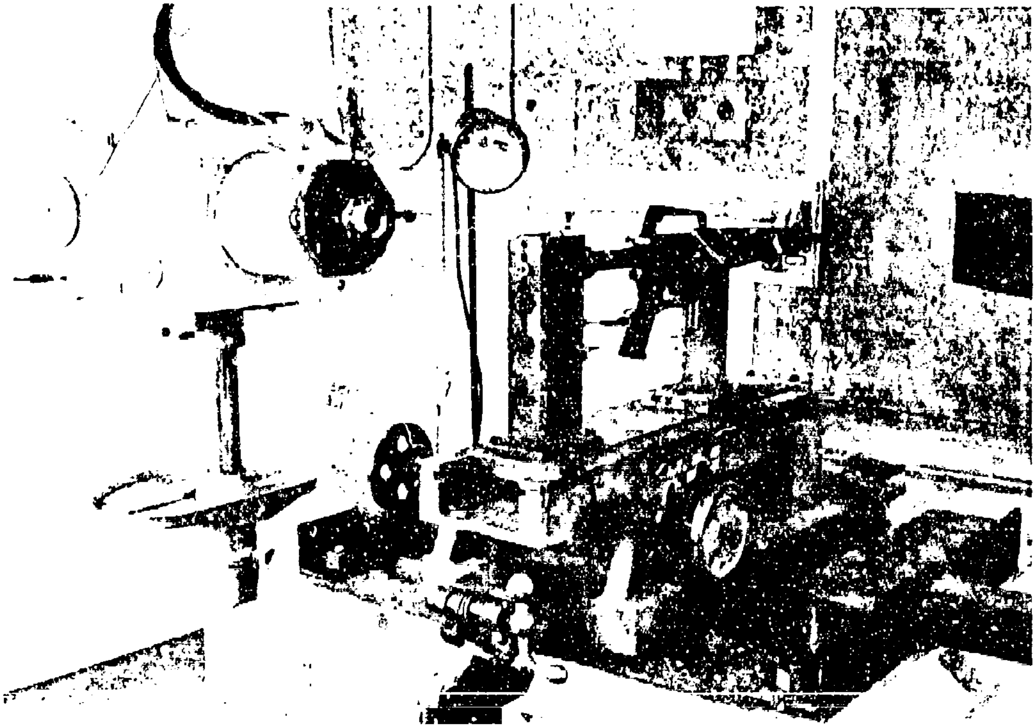


Figure 1. Displacement-time camera being employed during product improvement tests of a rifle.

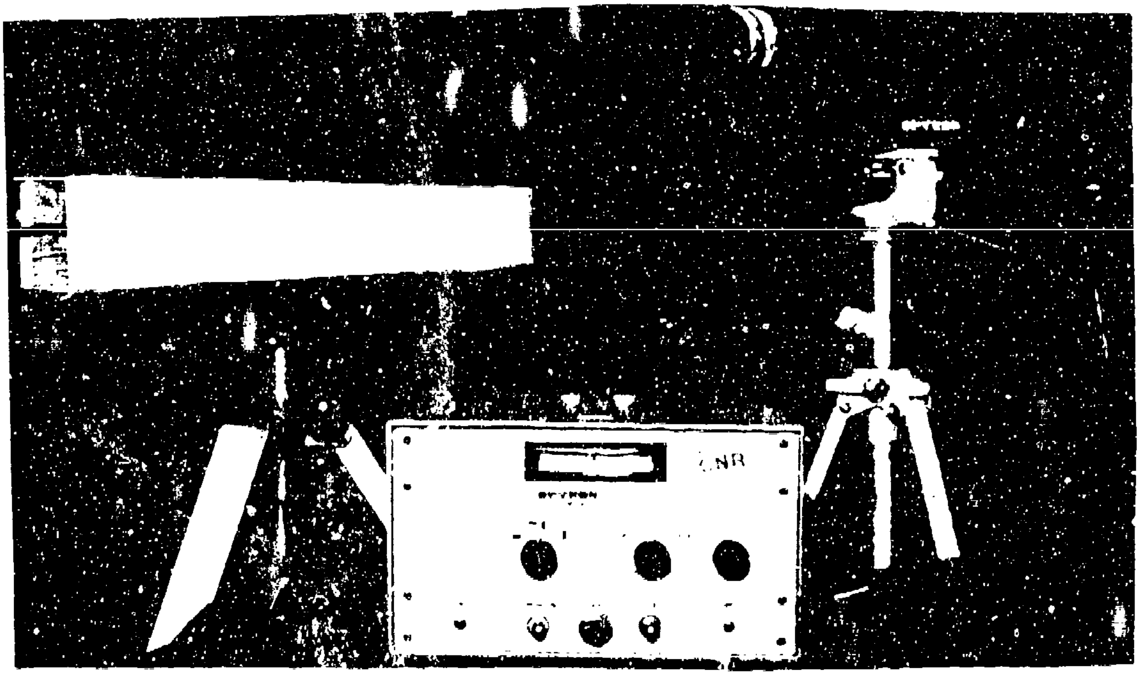


Figure 2. Components of the Optron optical tracker.

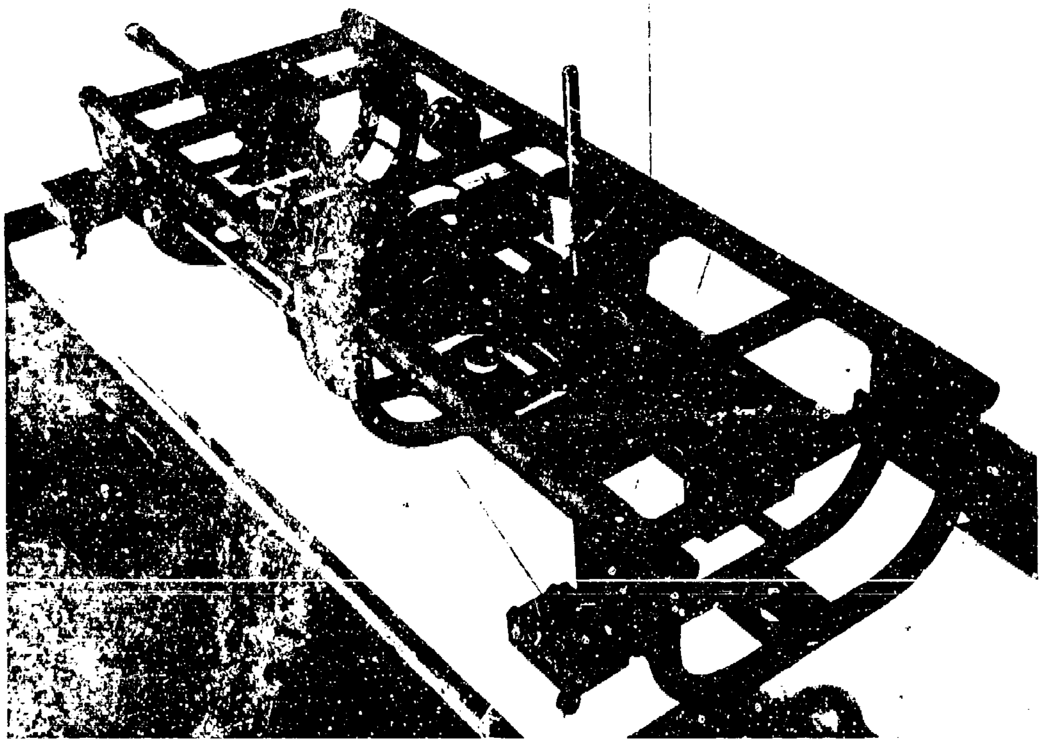


Figure 3. Ballistic pendulum employing a five-wire suspension.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities

ITEM	REQUIREMENT
Weapon mount	
Linagraph 809 photographic paper	
Linagraph 1000 liquid processing kit	
Variable height table	to support recording paper
Developing pans	
Drum-type photograph dryer	
115-volt, 60-cycle electrical source	
Solenoid or other apparatus	for firing weapon
Power source for solenoid	
Ballistic pendulum cradle	with stylus
Mounting brackets	to assemble weapons within cradle
Indoor firing facility	with overhead supports for three- and five-wire suspensions

2.2 Instrumentation.

ITEM	PERMISSIBLE ERROR OF MEASUREMENT*
Optron electro-optical device Displacement-time camera Burst control unit Sequence timer Electronic timer Cyclic-rate recorder Infrared sensor	System resolution is from 0.1% to 0.02% of lens displacement

3. REQUIRED TEST CONDITIONS.

3.1 Displacement-Time Measurement.

3.1.1 Optical-Mechanical Test Conditions. The displacement-time camera uses an optical-mechanical system for recording displacement along a straight line as a function of time. The displacement-time camera is basically similar in design to a box camera except that the film is mounted on the surface of a variable-speed revolving drum and is a sensitive photographic paper. Reflected light from a small reflector mounted on a component of the test weapon, passes through the lens of the camera and is condensed into an intense spot. This strikes the photographic paper on the revolving drum, making an accurate record of the movement of the part.

The dynamic characteristics of the component with a small reflector mounted on it should not adversely affect the performance of the test weapon, nor will they prevent its meeting the specifications of the requirements documents.

3.1.2 Electro-Optical Test Conditions. The Optron consists of the head unit, which is the camera, and the control box that contains the power supply as well as the input, output, and control electronics. Figure 2 shows the head and the control box of the Optron, as well as a typical light source. The head has a lens that allows it to be focused on a target and a viewfinder that permits the operator to look at the target. The lens mounts by means of an adaptor to the standard Leica threads on the head unit. The viewer on these units must be lowered to allow the operator to see through the lens; however, the newer units have a fixed viewer which eliminates the problem of forgetting to raise the viewfinder before attempting to make a measurement.

The control box has an analog meter on which the operator can read either the DC output, the light intensity at the target, or the peak amplitude of the output. The meter is also used to aid in locking the Optron on the target once the lighting and target orientation have been chosen. The input to the meter is controlled by the switches and potentiometers on the front panel. The output of the Optron taken from the control box can be recorded on analog tape or acquired digitally with a dynamic range of ± 5 V. The frequency response is 25 to 50K Hz, but the signal may be low pass filtered by internal filters at 1, 10, 100 1K, 10K Hz selected from the front panel.

*The permissible error of measurement for instrumentation is the two-sigma value for a normal distribution; thus, the stated errors should not be exceeded in more than 1 measurement of 20.

As with other electro-optical trackers, the Optron is designed to track a discontinuity within its field of view. This discontinuity is a distinct interface between a dark and light area which may be created by at least two methods. Using white tape or paint to create a target on an inherently dark subject and lighting this target from the same side where the Optron is positioned creates a front-lighted target. A back-lighted target is created by positioning a diffuse light source behind a dark target and aiming the light directly at the Optron lens. The Optron is then focused on the edge of the target, giving a very sharp edge for the tracker to follow. Whenever possible, the back-lighted target technique is used because a cleaner signal due to the well defined edge that is created can be obtained. In both cases, the light source must be a DC light, as the tracker will pick up and amplify any AC component in the light source.

Figure 4 shows what the operator sees through the viewfinder as well as the tracking axes which are not visible to the operator. The width of the target must be at least 10% of the lens displacement. The smaller square visible through the viewer represents 100% of the lens displacement. The electronics allows for 100% over range in the displacement as represented by the larger square, but the linearity is not guaranteed in this section of the viewer. It is recommended that the Optron be set up so that the maximum displacement anticipated falls within the 100% range. Figure 5 shows the viewfinder with the target visible through the sight. The Optron has two tracking axes and the target may be oriented orthogonal to either axis depending on the direction of the displacement which must be measured. The head may be rotated within the holder which allows for measuring displacements other than horizontal and vertical. The black and white interface may be oriented either white over black or black over white for the vertical axis, and white left of black or white right of black for the horizontal axis. On the front panel of the control box is a switch with which the operator selects the target orientation.

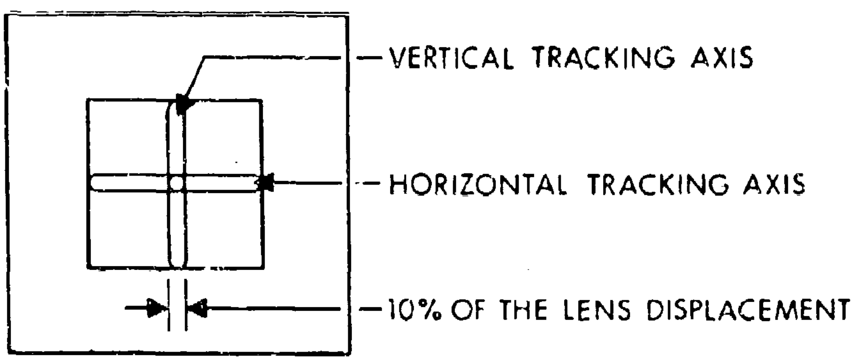


Figure 4. Optron viewfinder.

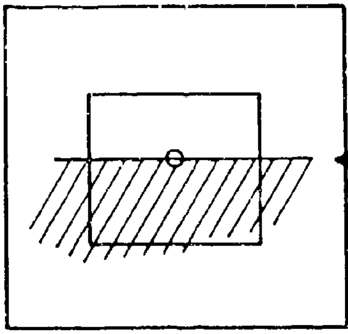


Figure 5. Optron viewfinder with target.

3.2 Impulse-Recoil Measurements. Recoil momentum of small-caliber weapons is measured by using three- and five-wire ballistic pendulums. The recoil momentum of the test weapon shall not exceed that stated in the requirements documents or appropriate safety standards, whichever is less.

Various types of ballistic pendulums can be used for measuring recoil; this TOP, however, is concerned with the five-and three-wire suspended pendulums. The basic theory and techniques of application are based on a report from Ballistic Research Laboratories (App A, ref 2). Since a five-wire suspended pendulum eliminates all motion except movement in the longitudinal direction, it is usually used when measuring recoil. In tests of weapons with muzzle attachements, such as compensators that reduce "climb" of the muzzle during automatic fire, it is desirable to determine two or three components of linear momentum. A three-wire suspension system is used under these circumstances. This type of suspension allows the pendulum cradle to move in two planes, the lateral rotation and as with the five-wire system, the longitudinal.

4. TEST PROCEDURES.

4.1 Displacement-Time Measurement.

4.1.1 Optical-Mechanical Procedures.

4.1.1.1 Preparing the Weapon for Test.

a. A reflector is mounted on the moving part(s) to be studied. If the part is hidden from view within the receiver (basic component), ports must be cut in the receiver to permit the camera to view the reflector. Particular care must be taken not to cut the viewing port in such a manner or location that the receiver is weakened or the movement of the part is affected.

b. The shapes of reflectors normally used are either cylindrical or hemispherical. The cylindrical reflector can be made from a short length of chrome-plated rod or a section of a needle. The hemispherical reflector can be made from a segment of a polished ball bearing. Either type reflector is soldered or cemented with epoxy to the moving part in such a manner that no bending or similar movement occurs. In most evaluations, a 0.2- to 0.3-cm (1/16- to 1/8-in.)-diameter reflector is used, depending upon the size of the part being studied. These small-diameter reflectors are used for two reasons: (a) to minimize the weight added to the moving part and (b) to minimize the movement of the highlight around the reflector as the part moves. The use of flat black paint on the areas around the reflectors is recommended to minimize reflections that will produce undesired traces on the film.

c. The weapon normally is fired from a rigid or semirigid mount similar to that shown in Figure 1. This is accomplished to minimize movement of the weapon so that the traces recorded from the reflectors show the exact movements of the part relative to the receiver or basic component. It is advisable to place a reflector on the receiver (as well as the part) to record any movement which may result.

4.1.1.2 Aligning and Positioning the Displacement-Time Camera. To produce a meaningful and accurate record, the camera lens, the axis of the revolving drum in the camera, the light source, and the path of movement of the part being studied must be in a common plane. Also, it is imperative that the path of movement of the part be parallel to the axis of rotation of the drum. In aligning the camera with the weapon, remove the drum housing and position a translucent plate made of ground glass across the rear of the camera in the same plane as the surface of the drum. The weapon is then hand-cycled, and the movement of the reflector is viewed on the plate as it is to be recorded on the photographic paper. Particular care must be taken to assure that the entire travel of the reflector is contained within the field of view of the camera and is within a 25-cm (10-in.) deflection across the surface of the plate. This is accomplished by adjusting the position of the lens with respect to the drum and changing the distance between the lens and the reflector. The lateral and vertical position of the image is adjusted by means of thumbscrews on the lens support. The distance between the lens and the reflector may be shortened by tubular extensions that are available for attachment between the body of the camera and the lens support assembly.

4.1.1.3 Operating the Camera. After the weapon has been prepared with the attachment of reflectors and the camera has been properly positioned and aligned, the required speed of rotation of the drum, sliding-shutter time, and displacement ratio must be determined before a formal record can be made.

a. Drum and Paper Speed. The required speed of rotation of the drum depends upon the cyclic time of the part being studied. The shorter the cyclic time, the greater must be the speed of the drum to preclude superimposition of the traces, particularly in the areas where a part changes direction. Caution must be observed; if the drum speed is too great, the drum will rotate before completion of a part motion, and recorded traces will overlap. The paper speed can be calculated through the use of an electronic timer that counts the revolutions per minute or the time for one revolution. The circumference of the drum is 97.8 cm (38.5 in.), and the speed is controlled with the variable speed motor within the camera.

b. Shutter. A sliding shutter located on the surface of the drum housing must be sequenced with the firing of the weapon, and the open time must not exceed the time for one revolution of the drum, or the traces will overlap. The shutter normally is controlled by an electronic sequence timer, but it can be hand-operated.

c. Displacement Ratio. Before making a formal record, determine a displacement (travel) ratio scale. This can be accomplished with a calibrated bar consisting of a series of reflectors at known distances apart. The calibrated bar is placed in the line of motion and photographed for one revolution of the drum which photographs as a series of straight lines. Then, by measuring the distance between the lines and comparing with the known distance on the calibration bar, a ratio of actual travel to recorded travel on the photographic paper can be calculated. This ratio or constant is referred to as the magnification factor (K_m) and is calculated using the following equation:

$$K_m = \frac{D_c}{D_f}$$

K_m = Magnification factor
D_c = Distance on calibrated bar
D_f = Distance on film

Since the camera normally cannot be set up on a one-to-one ratio with the weapon, the magnification factor is used with all calculations involving a distance measured from the film. Use of this constant also minimizes the error from distortion caused by the optical system and corrects for paper shrinkage during development.

d. Timing Lines. Precise timing lines from a light source within the camera are photographed on each record. For most applications, the light source is pulsed 100 times a second, making the timing lines 10 milliseconds apart. The lines should be positioned on the record to avoid interference with reflector traces, but as close as possible to the trace to minimize error. The timing light can be rotated about its vertical axis to position the lines on the record.

4.1.1. Developing the Photographic Record. After a trial has been conducted, the drum housing must again be removed and taken to a dark room for removal and developing of the photographic paper. Care must be exercised during processing of the film, particularly in the developing bath. Too long a time in the developing solution will darken the record (or turn the entire record black, making it unreadable). With the bath at a temperature of 45° C (105° F ±5°), the photographic record should be in the developing solution 8 to 10 seconds and immediately put into the stop bath. The process of loading the camera and removing and developing the record should be accomplished in total darkness; use of red lights will cause the record to turn gray from exposure.

4.1.1.5 Sample Records.

a. A portion of a displacement-time record showing the recoil of the bolt-carrier in a rifle firing ball and tracer ammunition is shown in Figure 6. The reflector was attached to the bolt carrier during this firing. Note the timing lines across the top of the record.

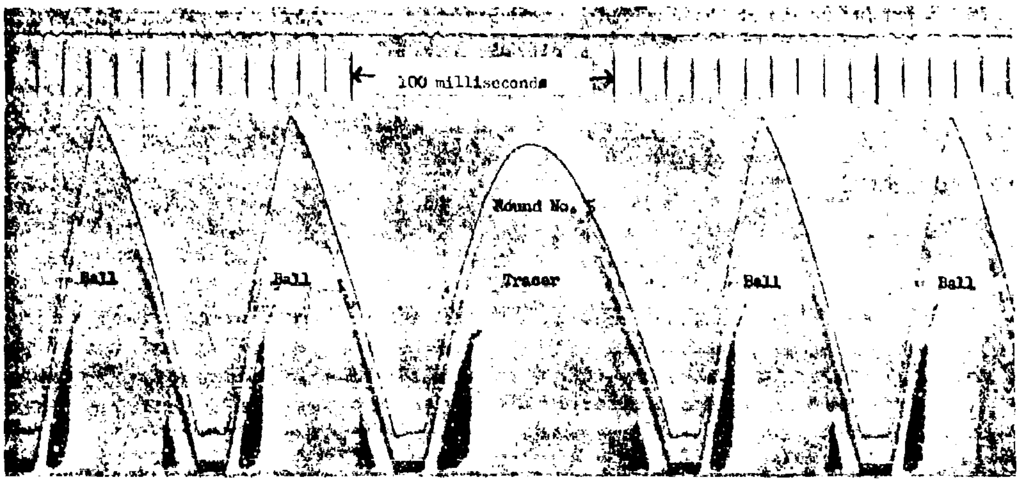


Figure 6. An incomplete recoil cycle resulting from firing a tracer cartridge in a rifle.

b. A portion of a displacement-time record extracted from a test of 30-round magazines fired from a rifle during automatic fire is shown in Figure 9. Reflectors were mounted on the magazine follower and bolt carrier of the rifle. With the direction of travel of the magazine follower vertical and the bolt carrier horizontal, a prism was used to orient the reflected path of movement of the bolt to the vertical plane. (The timing lines, which were recorded along the lower edge of the record, have been cut off to reduce the size of the photograph. The distance traveled in 10 milliseconds is sh[illegible] at the lower right.)

4.1.2 Electro-Optical Procedures.

4.1.2.1 Setting up the Optron. Several items must be considered when setting up the optical tracker, such as the resolution desired, any restrictions on how far away the Optron must be placed from the target, and the anticipated displacement of the target. To obtain more resolution while maintaining a safer distance from the gun tube, a longer focal length lens could be used. The resolution is 0.1% to 0.02% of the lens displacement. It is possible to obtain resolution greater than 2×10^{-7} m; however, it should be noted that the dynamic range is reduced with increasing resolution. Ultimately, either the resolution is limited by the displacement which is to be measured, or the displacement is limited by the required resolution. If the anticipated displacement is oscillatory about the rest position, the target may be aligned in the center of the viewfinder, and if the displacement is expected to be mostly or totally to one side of the rest position, the target should be off-set to one side to allow the Optron to follow the displacement through the tracker's full dynamic range. While aligning the head, consideration should be given to the stability of the stand to which the head is attached. Head motion caused by blast will affect the measurement and should be avoided by the use of heavy camera stands and sandbags if necessary. If the expected overpressure is sufficient to cause concern, the Optron head unit should be shielded from the environmental factors.

4.1.2.2 Lighting the Target. Once the target has been established and the location of the head has been determined, it is necessary to light the target. As mentioned earlier, a DC light source is used. It is important to evenly illuminate the target area as variation in light intensity may be interpreted as motion of the target. To determine the light intensity required for the Optron, place the meter switch on the control box in the light position and place the lens cap on the lens. Now adjust the lock-on control so that the meter reads -20%. Open the lens cap and look through the sight. To measure the light intensity on the target, the center circle in the viewer must be entirely in the white area of the target. Raise the viewer and adjust the aperature ring of the lens to cause the meter to read somewhere between +18 and +40%. If a back-lighted target is to be used, the light source should usually be covered with a diffusive material to spread the light out more evenly. Variations in the intensity of the light source as the target moves across the source will affect the accuracy of the output.

4.1.2.3 Locking on the target. Once the lighting is set up, the next step is locking on the target. This is accomplished by first placing the meter switch on "OP". Turning the lock-on control counterclockwise will eventually result in the meter jumping off scale to the right. Turning the lock-on in a clockwise direction will lead to a meter reading somewhere on the scale. Continuing to rotate the control clockwise will cause the meter to jump off scale on the left side. The best lock-on position lies somewhere between the point where the meter falls off scale on the left and the point where it falls off the scale on the right.

A better method of locking onto the target is to look at the output on an oscilloscope and place the lock-on control where the noise in the output is minimized within this range. Manually moving the target, if possible, through the full scale of the anticipated motion and observing the tracker output on the oscilloscope will reveal if the lock-on is satisfactory and if the position of the Optron will allow the tracker to follow the motion which is to be measured.

4.1.2.4 Calibration Factor. The procedure to determine the calibration factor is to move the target through some portion of the anticipated displacement by a variety of methods, depending on the application. The output of the Optron is recorded while the displacement is measured by some alternate method such as a dial indicator. This not only provides a calibration factor but also a check on the linearity of the system. Sometimes it is impossible to move the device being tested in a controlled manner that lends itself to a quasi-static calibration. If this occurs, it is usually possible to simulate the motion by sliding a surrogate target along the test item at the same distance from the head and measuring the displacement of this target.

4.2 Impulse-Recoil Measurement.

4.2.1 Mounting Weapon in Pendulum Cradle.

a. The weapon must be mounted in the pendulum cradle so that the centerline of the gun barrel lies in the plane of support, an imaginary plane across the top edge of the blocks used for attachment of the suspension wires. The center of gravity of the cradle after mounting the weapon must also lie in the support plane and be equi-distant between the attaching points of the front and rear suspension wires. The latter is achieved by balancing the pendulum with the movement of weights longitudinally, laterally, and vertically. The pendulum

cradle is balanced by use of a beam balance as shown in Figure 7. Before balancing, it is suggested that calculations be made to estimate the recoil distance of the pendulum. The weight of the pendulum should be so that the maximum displacement is 25 to 30 cm; 10- to 25-cm displacement is recommended. The following equation can be used for the calculations:

$$W_p = \frac{50 \times g \times I \times T}{D \times \pi}$$

W_p = Weight of pendulum in kilograms

I = Impulse in Kg-sec. This can be estimated by using

$I = P_m \times P_v$ + (5% to 10% to allow for muzzle gases);
P_m = projectile mass = (projectile weight)/g;P_v = projectile velocity in m/sec

g = 9.8055 m/sec2

T = Estimated time of pendulum period. The equation

$$T = 2\pi\sqrt{\frac{L}{g}}$$

can be used, in which L = length of suspension wires in meters

D = Displacement in cm

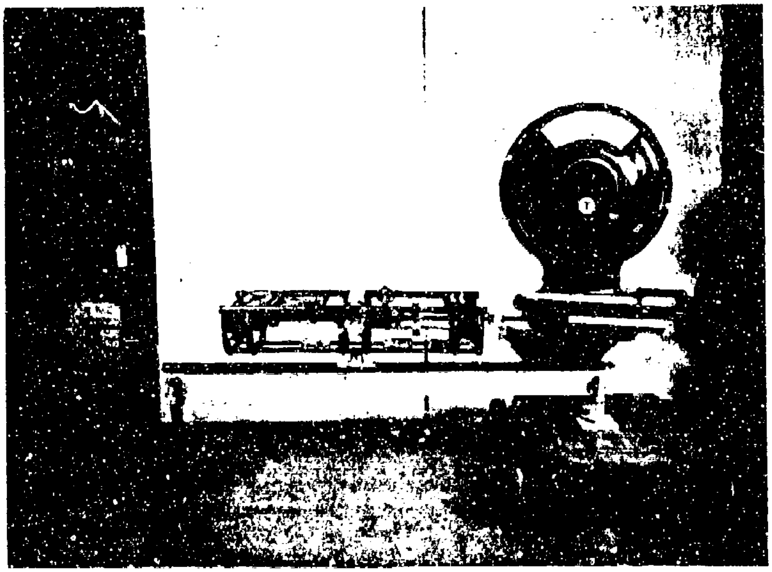


Figure 7. Pendulum cradle on beam balance.

b. During the balancing process, the pendulum cradle is supported alternately on the attaching point for the stylus and on a bracket that attaches opposite the center suspension wire. These locations are indicated in Figure 8. The cradle is supported on the beam balance at either of the two locations and then rotated through 90° and 180° turns parallel with the axis of the cradle. The movable weights are adjusted until no deflection of the dial indicator on the scale results with rotation of the cradle. The cradle is then supported from the second location and the procedure repeated. This balances the pendulum cradle in all three dimensions (longitudinally, laterally, and vertically) and shifts the center of gravity of the cradle to a point that lies in the support plane, equidistant between the attaching points of the front and rear suspension wires and equi-distant between the center suspension wire and a line between the front and rear suspension wires.

4.2.2 Preparation for Firing. After the weapon has been assembled in the pendulum cradle and balanced, the cradle is suspended by either five or three wires, depending upon the measurements to be recorded. The support plane of the cradle must be level. This is accomplished by shortening or lengthening the supporting wires. The next step is to determine the period (time for one complete cycle) of the ballistic pendulum. The pendulum is manually displaced rearward 15 to 20 cm (6 to 8 in.) and released. To attain a smooth release with no external effects, the pendulum is retained in the rearward position with a piece of string. The string is then burned to start the cycle. At least 10 continuous periods are timed with sweep-second-hand stopwatches by two individuals. This is repeated five times, and from the data obtained the average period are calculated.

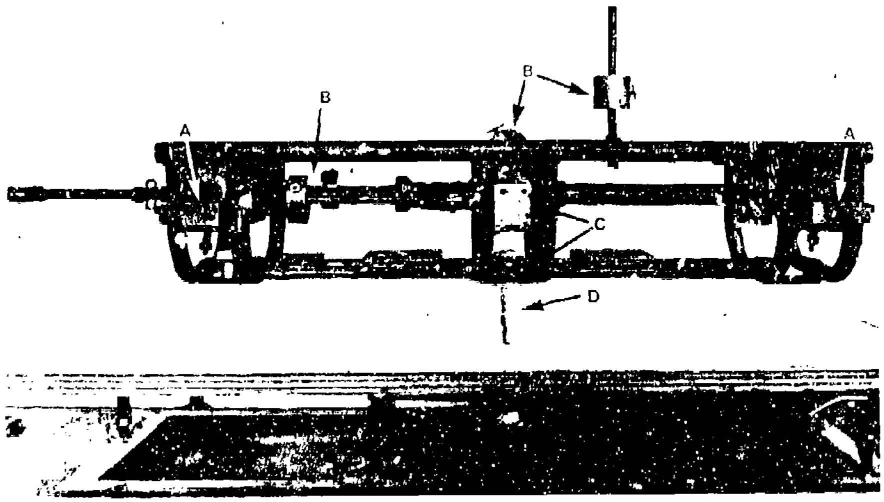


Figure 8. Rifle mounted in five-wire ballistic pendulum.
A - Support Plane, B - Movable Weights for Balancing the Pendulum,
C - Suspension Points Used During Balancing, D - Stylus.

4.2.3 Firing the Weapon and Recording Data.

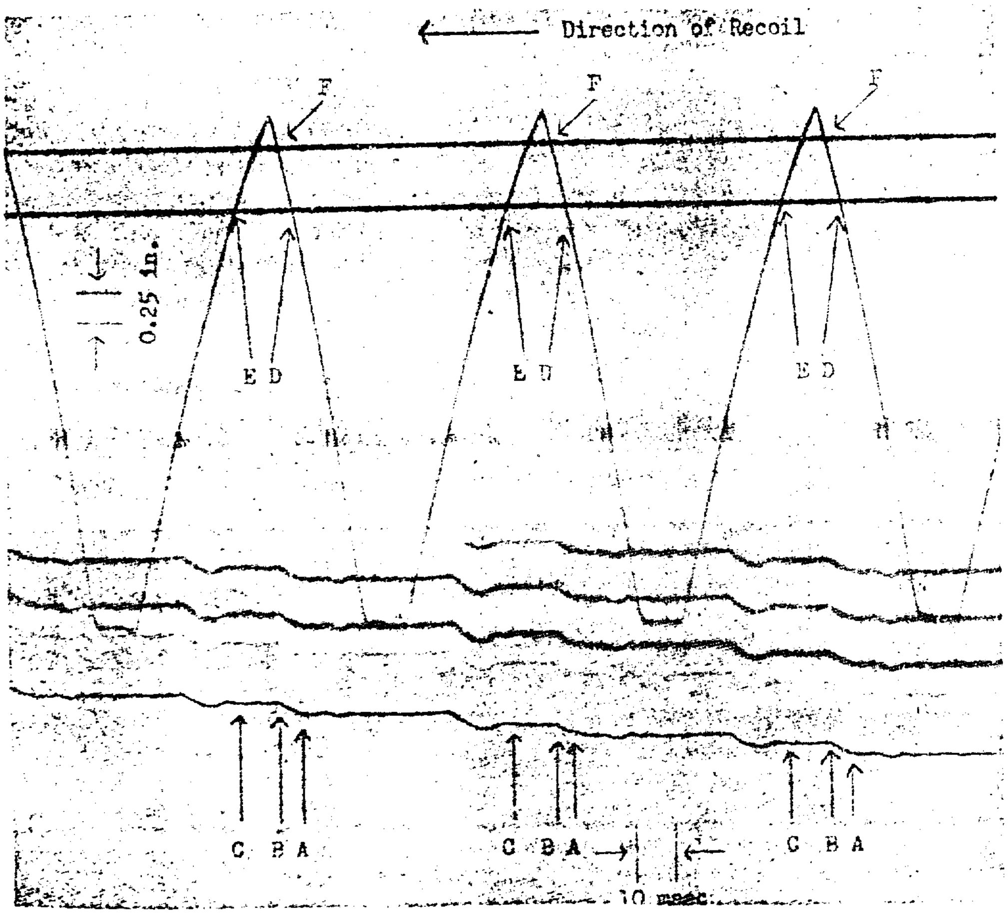
(1) Actuation of the trigger on the weapon must not induce movement to the pendulum. This is normally accomplished by a solenoid or similar device. Also, if the trigger-actuating device is electrically operated, the connecting wires must not retard the movement of the pendulum.

(2) When the weapon is fired, the movement of the pendulum is recorded on tracing paper by a stylus assembled to the bottom side of the cradle. The stylus is directly below the center of gravity of the pendulum. In this location, particularly when using the three-wire suspension, two components of linear impulse can be recorded because the deflection of the pendulum cradle (other than directly rearward) occurs as a rotational movement around the center of gravity of the cradle. This causes an angled deflection of the cradle; hence, the compensator forces from the muzzle attachements can be measured.

5. DATA REQUIRED. Record the following:

5.1 Displacement-Time Measurement.

a. Identification of weapon and mount and part being measured
b. Magnification factor (optical-mechanical device only; see para 4.1.1.3.d)
c. Amount of displacement versus time (or photograph)



A to B = Follower elevates round into position for feeding.
B to C = Round in stable position awaiting engagement of bolt in counterrecoil.
D = Bolt clears base of round in magazine during recoil.
E = Bolt engages base of round during counterrecoil.
F = Position to which bolt must be recoiled to engage bolt catch.

Figure 9. Displacement-time record of rear of magazine follower and rifle bolt during automatic fire. A, B, and C indicate magazine follower; D and E indicate bolt trace relative to the base of the round in the magazine.

5.2 Impulse Recoil Measurement. Obtain the following:

a. Weapon identification

b. Pertinent characteristics of pendulum

c. Time of each pendulum period and average period (4.1.3.2)

d. Measurements from traces (4.1.3.3)

6. ANALYTICAL PLAN.

a. The stylus records the chords of the half swings (rearward and forward) of the pendulum cradle. To correct for friction of the stylus on the paper and bending resistance of the suspension wires, four half swings (both rearward and forward) usually are recorded. The amplitude of each half swing vs the number of the swing is then plotted on a graph and extrapolated to zero to obtain the "frictionless" chord length. A sample plot is shown in Figure 10.

b. From the frictionless chord length and the previously measured time for one period of the pendulum, the impulse of the pendulum can be calculated with the following equation:

$$I = \frac{C \times M_p \times \pi}{50 \times T}$$

I = Impulse in Kg-sec

C = Frictionless chord length in cm

M_p = Mass of pendulum = W_p/g, in which W_p is the weight of pendulum in kilograms and g = 9.8055 m/sec2

T = Time for one period of pendulum in seconds

c. Using the calculated impulse of the pendulum, calculate the recoil energy of the weapon with the following equation:

$$R = \frac{I2}{2M_w}$$

R = Recoil energy of weapon in m-Kg

I = Impulse of pendulum in Kg-sec

M_w = Mass of weapon = weight of weapon in kilograms/g

7. DATA PRESENTATION.

The extent of data analysis depends upon the specific objectives of the test program. In general, the film is examined, and the beginning and completion of related events are noted on samples of film in the manner shown in Figure 9. The velocity of the part being studied is taken from the tangent of the displacement-time curve at the applicable point. From this, momentum and other energy measurements can be calculated.

$$\text{Momentum (Kg-sec)} = \frac{\text{weight of part in Kg} \times \text{velocity in m/sec}}{9.8055}$$

$$\text{KE (m-Kg)} = \frac{\text{weight of part in Kg} \times (\text{velocity})^2}{2g}$$

The acceleration is the time rate of change of velocity and, for the condition of Figure 4, can be determined. Data reduction equipment is available which can examine the displacement-time curve and determine acceleration, in m/sec2, including maximum acceleration. (Accelerations can also be determined by plotting velocity versus time. The tangents will provide accelerations.)

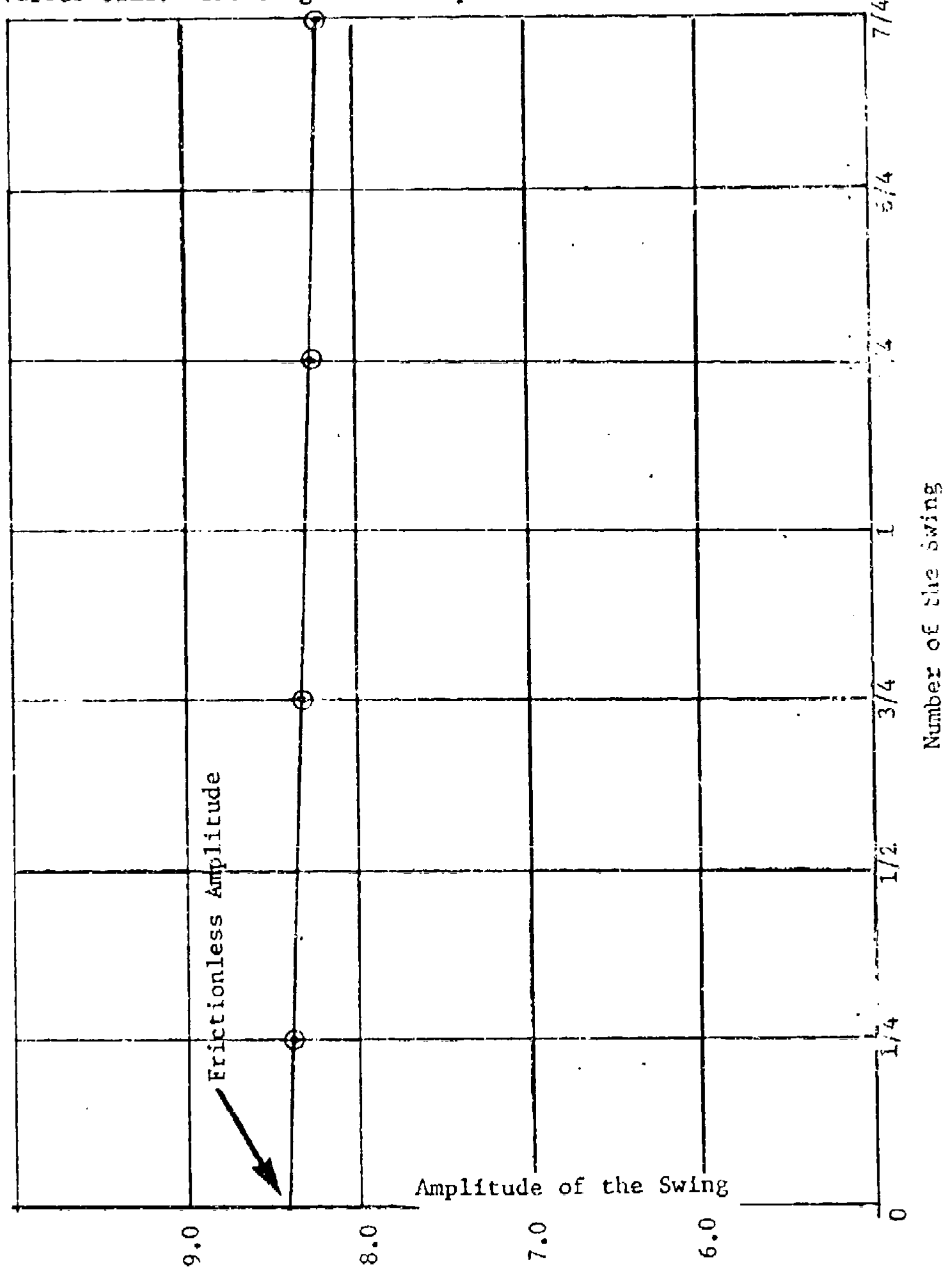


Figure 10. Method of determining frictionless amplitude of the swing.

Rate of fire, displacement, delay time, etc., are also readily determined from a trace such as Figure 9.

At least three measurements should be made of each parameter when performance appears repeatable. When performance is erratic, enough measurements should be obtained to calculate a mean and a standard deviation.

Recommended changes of this publication should be forwarded to Commander, U.S. Army Test and Evaluation Command, ATTN: AMSTE-AD-M, Aberdeen Proving Ground, MD 21005-5055. Technical information can be obtained from the preparing activity: Commander, U.S. Army Combat Systems Test Activity ATTN: STECS-AD-A, Aberdeen Proving Ground, MD 21005-5059. Additional copies are available from the Defense Technical Information Center, Cameron Station, Alexandria, VA 22304-6145. This document is identified by the accession number (AD No.) printed on the first page.

APPENDIX A
REFERENCES

1. "Final Report on Initial Production Test of Magazine, 30-round, for M16A1 Rifles", Miller, F.H., Report No. APG-MT-3547, June 1970.

2. "Measuring Displacements of Gun System Components by the Use of Optron Optical Trackers", Haug, B.T., Memorandum Report ARBRL-MR-03331, June 1984.